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Ambient climate and soil effects on the headspace under clear mulch film

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ABSTRACT

Clear degradable mulch film (CDMF), when installed over a newly sown crop, fundamentally alters the growing environment through the entrapment of heat and CO_2, the attenuation of incident solar radiation and, the capture and return of evapotranspiration losses back to the soil. These changes can be harnessed by farmers in a variety of ways to increase crop production through, for example, earlier sowing and more rapid crop establishment, reduced frost risk, geographical expansion of a crop into new areas otherwise unsuited to that crop, and soil water conservation in low rainfall areas. Conversely, when used at the wrong time of year, the temperatures under the film can reach levels that result in plant heat stress. This paper reports on an investigation conducted in southeast Tasmania into how key headspace climate variables (daily maximum and minimum temperatures, relative humidity, total daily radiation and atmospheric CO_2 concentration) under CDMF respond to changing ambient climatic conditions and underlying soil characteristics. The film fundamentally altered the growing environment with incident solar radiation reduced by up to 34%, daily maximum temperatures reaching a peak of ~60 °C, daily minimum temperatures up to 20 °C above ambient levels in summer and, atmospheric CO_2 concentrations up to 100 times ambient levels. The magnitude of these responses was all sensitive to soil type. Simple models were derived for predicting daily headspace solar radiation, maximum temperature and minimum temperature from readily available ambient data. These models can be used to identify site-specific, operational limits for film application and, when integrated into farm system models, enable the prediction of wider production and environmental impacts under film.

1. Introduction

The world population is projected to increase from 6.8 billion in 2010 to over 9.1 billion by 2050, with an expected increase in food demand of 70% (FAO, 2009). This presents a major challenge for agricultural production, especially in areas where crop production is likely to be adversely affected by climate change. Furthermore, options for increasing crop production in developed countries are diminishing. With improved management, yields are approaching their environmental potential and, while gains can be expected from improved plant breeding, farmers will need a range of management and technological options to assist them in increasing production and adapting to climate change. One potential technology is clear degradable mulch film (CDMF).

CDMF is typically made from a thin layer of impervious and stretchable petroleum-based polyolefin or bio-derived materials such as starch-based polymer or other combination materials that degrade within a timeframe governed by the chemical properties of the film and the environmental conditions to which they are exposed.

In crop applications, strips of the film are typically laid over a newly sown crop and the edges buried on either side with soil; the volume of air between the soil surface and the film is referred to as the headspace. The film acts like a glasshouse during the early stages of crop growth capturing and concentrating soil and plant CO_2 and O_2 emissions (Rubin and Benjamin, 1984; Sheldrake, 1963, Perez et al., 2005; Pan et al., 2003), recycling evapotranspiration (ET) losses back to the soil (Brown et al., 1991, Dubois, 1978, Wang et al., 2005), attenuating incident solar radiation (Loy et al., 1989; Carruthers, 2004, Vox and Schettini, 2007, Vox et al., 2004) and trapping outgoing terrestrial radiation leading to increases in above and below ground temperature (Miller and Bunger, 1963; Aguyoh et al., 1999; Courter et al., 1969; Brown et al., 1991; Keady, 2001). During the period of cover, incident rainfall is diverted away from the crop and concentrated in the uncovered space between film strips where a portion will enter the soil and becomes available to the current or subsequent crop. The magnitude of these effects will vary with location, time of year, soil type and CDMF characteristics. These

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effects are temporary as eventually the plants emerge through the film as it breaks down (or is manually perforated) and continue to grow under the prevailing ambient conditions.

Temperature increases under plastic film would be expected to generally promote growth and development, provided the increases are not too high (i.e. approaching or exceeding critical temperatures for plant growth). There are a range of studies that report faster and higher rates of crop establishment and earlier maturation under polymer film (e.g. Sweet corn — Orzalek et al., 2000, Melon – Rosa-Ibarra et al., 2005, Strawberry — Singh et al., 2007, Wheat - Li et al., 1999, Potatoes — Lamont et al., 2005, Asparagus — Marco-Arboli and Diaz-Serrano, 2005). The higher temperatures and potentially faster crop establishment under CDMF can be used to grow crops outside their typical environmental thresholds. For example, in higher latitudes where crop establishment dates are limited by frost or low temperatures, plastic film has the potential to enable earlier establishment, better use of the longer summer days and reduced risk from late frost events due to earlier maturation (e.g. sweet corn production in Newfoundland — Kwabiah, 2004). In Australia field trials have shown that CDMF can be used to enable earlier sowing, establishment and hence maturation of cotton crops so as to reduce exposure to late season heat stress (Brown, 2014). The potential for season length manipulation under plastic films enables producers to harvest earlier and get their product on the market earlier than competitors and to take advantage of price premiums (e.g. potato in Tasmania, Lisson, 2009). Soil water conservation under and rainfall concentration alongside film strips can potentially be harnessed in low rainfall locations or seasons to enable earlier sowing, alternative higher value crops (otherwise limited by water availability), improved/faster establishment and increased yield potential (Lisson et al., 2010; Wang et al., 2005).

Farmer decisions relating to whether or not to use CDMF and if so, the optimum management of the film-based 'system', are complex and multi-facetted. As noted above, film can fundamentally alter the growing environment of the crop and hence influence a wide range of management decisions such as crop selection, sowing time, harvesting arrangements, fertilizer and weed management. Spatial variability in soil characteristics and seasonal climate plus longer-term trends in climate change add to the complexity of decision making. One potential way of dealing with this complexity is through the use of agricultural system models that simulate production by combining soil, plant and manager modules to describe the specific processes within the system under investigation. Such models provide a valuable 'tool' to help farmers and scientists to explore the complex biological, physical, management and economic impacts (and associated interactions) of CDMF and to identify best-bet season and site-specific management practices for film-based crop production (Lisson et al., 2010). These system models are typically driven by historical, site-specific, daily climate inputs of air temperature (minimum and maximum), incident solar radiation and rainfall (e.g. APSIM, Keating et al., 2003). Hence, modelling crop growth and development under-film requires a component model for predicting headspace climate from ambient conditions. Such a model needs to be derived from robust, 'generic' relationships that are applicable across a range of production environments. This, in turn, requires data covering a wide range of ambient climate, day-length and soil conditions.

Furthermore, temperatures of the headspace and soil are key determinants of the rates of above- and below-ground film degradation. Hence the development of predictive models for film degradation will require both ambient and sub-film climate input data. Previous modelling of the sub-film environment has focussed on prediction of soil temperature profiles under black mulch film (Wu et al., 1996). This standalone soil temperature model requires a wide range of soil chemical and physical parameters, film optical properties and historical, short-interval ambient climate data. Intensive model input requirements are restrictive when it comes to conducting exploratory simulations across a wide range of environments and similarly are not likely to be met for the purposes of decision support.

This paper reports on an investigation into how key headspace climate variables (daily maximum and minimum temperatures, relative humidity, total daily radiation and atmospheric CO_2 concentration) under CDMF respond to changing ambient climatic conditions and underlying soil characteristics. These findings are used to develop simple, generic models for predicting headspace climate variables from readily available, daily historical climate and other site-specific environment data. The longer term aim is to incorporate these headspace climate relationships into: 1) the agricultural system model APSIM (Keating et al., 2003) to enable prediction of the broader production and environmental impacts of film use; and 2) a CDMF degradation model currently under development.

2. Materials and method

A trial was established in August 2013 on four different soil types across two sites near Clifton Beach (42.59°S, 147.31°E) and Cambridge (42.79°S, 147.42°E) in southeast Tasmania. The soils were chosen to cover a range of soil physical, chemical and biological properties (Table 1).

Strips of soil (~4 m long × 2 m wide) to be covered with film were cleared of weeds and tilled uniformly in a north/south orientation to a depth of ~40 cm and wetted up artificially to field capacity (where necessary). The soil was then shaped into a mound and covered with strips of UV stabilized, clear polyethylene propagation film (3 m long × 1.2 m wide × 10 μm thick) manufactured by Integrated Packaging Pty Ltd., Melbourne. The edges of the film overlay were buried to a depth of ~15 cm to create a sealed headspace between the soil surface and the underside of the film. The headspace volume varied with soil structure and the amount of space between surface aggregates; the sand treatment ('single grain' pedality) had the smallest headspace volume and the clay treatment ('strong' pedality) the largest. The film was replaced every 3–4 months due to general wear and tear (i.e. bird and insect damage, film breakdown). At the time of film replacement, the soil was rewetted to maintain the field capacity soil moisture levels. Bird damage was more extensive and prolonged in the clay treatment resulting in a data gap from early December 2013 to early January 2014.

In order to examine the effect of soil moisture content on headspace climate, a separate 'dry' soil treatment was established (identical in all other respects to the 'wet' treatment) for the sandy loam soil at Cambridge. This was established in late summer when the soil reached air dry soil moisture content. The top 40 cm of the profile was underlain with plastic to prevent lateral and vertical moisture movement from the adjacent soil.

In order to broaden the genericity of the trial results and to remove the confounding effects of variable plant growth on the headspace climate, plants were not included in the trial. Plant growth under film is highly variable and is influenced by a range of factors such as species, time of year, soil characteristics, moisture content etc. Indeed, for much of the year growth under CDMF is prevented by supra-optimal temperatures. Hence over the 12 month duration of the trial and across the range of treatments imposed, the impact of plants on the headspace climate would be highly variable and inconsistent. Furthermore, CDMF

Table 1
Selected attributes of soil treatments (courtesy SWEP Analytical Laboratories).

Soil number	1	2	3	4
Name	'Sandy loam'	'Clay'	'Sand'	'Mudstone'
Location	Cambridge	Cambridge	Clifton	Clifton
Surface texture	Sandy loam	Heavy clay	Sand	Fine sandy light clay
Color	Brown	Brownish gray	Light gray	Grayish brown
pH (water)	5.6	7.1	7.0	5.6
Organic carbon (%)	1.5	3.2	0	2.4
Organic matter (%)	3	6.3	0	4.7